ogy Policy Institute tries to fill this gap by compiling R&D spending data on international cooperative projects sponsored by U.S. agencies (Wagner, Yezril, and Hassell 2001).

The RAND report finds that approximately $4.4 billion in R&D spending by Federal agencies involved a significant international content in FY 1997 compared with $70 billion in total Federal obligations for R&D work in that year. The vast majority of the spending involves scientist-to-scientist collaboration in joint research projects. Technical support to aid a foreign country was a distant second. The largest spending for binational R&D cooperation was identified in projects involving Russia, Canada, the United Kingdom, Germany, and Japan. Spending in collaborative R&D with Russia increased considerably since the dissolution of the Soviet Union, especially in aerospace and aeronautics. Other scientific and policy interests in this area of the world include containing nuclear materials and aiding the transition of Russian scientists from weapons to civilian research.

Spending in aerospace and aeronautics accounted for more than one-half of the U.S. R&D dollars committed to a single field of collaboration across all countries. Biomedical and other life sciences, engineering, and energy fields also received significant international support. In part, the preeminence of aerospace research in international research spending is due to the disproportionate share of NASA in these statistics, fully $3.1 billion of the reported $4.4 billion, including funding for large multicountry projects such as the International Space Station and the Earth Observing Satellite System. Undoubtedly, international R&D support provided by other agencies is somewhat undercounted. For example, DOD figures reported at $263 million are likely to be an underestimate due to data validation problems, according to RAND. NIH, NSF, and DOE also perform key international work with projects in human genetics, infectious diseases, geosciences, and other basic research and energy sciences.

In another approach, U.S. agencies have formed interagency research groups that subsequently pursue international activities. For example, the U.S. Global Change Research Program (USGCRP), in place since 1989, studies climate change and Earth ecosystems and performs some of its research and data gathering on an international basis.[46] The program authorized research funds of $758 million in FY 2000 from NASA, NSF, DOE, NOAA, USDA, and other agencies (Executive Office of the President 2001). Another $937 million was authorized in support of NASA's development of Earth-observing satellites and related data systems as part of USGCRP activities. (For a summary of recent efforts to more fully integrate the use of collaborative activities in the international S&E arena, see sidebar, "The NSB Task Force on International Issues in Science and Engineering.")

[46]For a description of international activities of the program, see <http://www.usgcrp.gov/usgcrp/links/relintpr.html>.

The NSB Task Force on International Issues in Science and Engineering

The National Science Board (NSB) is responsible for monitoring the health of the national research and education enterprise. In recent years, the importance of science and technology in the global context has grown. As a result, both private sector and government cooperation in international science and engineering have become more prominent.

The NSB took note of these developments in preparing its strategic plan (NSB-98-215), in which it observed that one of the most important challenges confronting the United States is how to deal with science and engineering in the global context. The National Science Board expressed the need for a fresh assessment of the roles and needs of science and engineering in the international arena, and for a coherent strategy that supports a productive relationship between scientific and foreign policy objectives.

The Board subsequently established the Task Force on International Issues in Science and Engineering to undertake this assessment. The task force was charged with examining the Federal policy role and the institutional framework that supports international cooperation in research and education, as well as NSF's leadership role in international S&E in the 21st century. The task force has organized symposia, workshops, and panel discussions with a broad array of experts and stakeholders and has conducted an extensive review of relevant policy documents and reports. Two interim reports will be followed shortly by a comprehensive National Science Board report on international science and engineering.

Further information about the work of the task force can be found on the Board's website at <http://www.nsf.gov/nsb/>.

International Comparisons of National R&D Trends

Absolute levels of R&D expenditures are indicators of the breadth and scope of a nation's S&T activities and are a harbinger of future growth and productivity. Indeed, investments in the R&D enterprise strengthen the technological base on which economic prosperity increasingly depends worldwide. The relative strength of a particular country's current and future economy and the specific scientific and technological areas in which a country excels, are further revealed through comparison with other major R&D-performing countries. This section provides comparisons of international R&D spending patterns.[47] It examines absolute and relative expenditure trends, contrasts performer and source structural patterns, reviews the foci of R&D activities within sectors, and looks at government research-related priorities. Although R&D performance patterns by sector are broadly similar across countries, national sources of support differ considerably. In nearly all OECD countries, government has provided a declining share of all R&D funding during the past decade, whereas the industrial share of the funding total has increased considerably. The relative emphasis of industrial R&D efforts, however, differ across countries, as do governmental R&D priorities and academic S&E field research emphases. Reflecting an overall pattern of R&D internationalization, foreign sources of R&D funding have been increasing in many countries.

Absolute Levels of Total R&D Expenditures

The worldwide distribution of R&D performance is concentrated in relatively few industrialized nations. Of the $518 billion in estimated 1998 R&D expenditures for the 30 OECD countries, fully 85 percent is expended in only 7 countries (Organisation for Economic Co-operation and Development 2000a).[48] These estimates are based on reported R&D investments (for defense and civilian projects) converted to U.S. dollars with purchasing power parity (PPP) exchange rates.[49] See sidebar, "Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data."

The United States accounts for roughly 44 percent of all OECD member countries' combined R&D investments; U.S. R&D investments continue to outdistance by 150 percent R&D investments made in Japan, the second largest R&D-performing country. The United States not only spent more money on R&D activities in 1999 than any other country but also spent as much by itself as the rest of the G-7 countries (Canada, France, Germany, Italy, Japan, and the United Kingdom) combined. (See figure 4-26 and appendix table 4-40 for inflation-adjusted PPP R&D totals for OECD and G-7 countries.) In terms of other large R&D performers, only South Korea accounts for a substantial share of the OECD total (a remarkable 3.8 percent in 1998, which is higher than the amounts expended in either Canada or Italy). In only four other countries (the Netherlands, Australia, Sweden, and Spain) do R&D expenditures exceed 1 percent of the OECD R&D total (OECD 2000a).[50]

In terms of relative shares, U.S. R&D spending in 1985 reached historical highs of 53 percent of the G-7 total and 48 percent of all OECD R&D.[51] As a proportion of the G-7 total, U.S. R&D expenditures declined steadily to a low of 49 percent in 1992. Since then, U.S. R&D has climbed to its 1999 level, a 53 percent G-7 share. (See figure 4-26 for actual expenditure totals.) Conversely, R&D spending in the United States was equivalent to 112 percent of spending in non-U.S. G-7 countries and to approximately 80 percent of all other OECD countries' R&D expenditures in 1999.

Initially, most of the U.S. improvement since 1993 relative to the other G-7 countries resulted from a worldwide slowing in R&D performance that was more pronounced in other countries. Although U.S. R&D spending stagnated or declined for several years in the early to mid-1990s, the reduction in real R&D spending in most of the other large R&D-performing countries was more striking. In Japan, Germany, and Italy, inflation-adjusted R&D spending fell for three consecutive years (1992, 1993, and 1994) at a rate of decline that exceeded similarly falling R&D spending in the United States.[52] In fact, large and small industrialized countries worldwide experienced substantially reduced R&D spending in the early 1990s (OECD 2000a). For most of these countries, economic recessions and general budgetary constraints slowed both industrial and government sources of R&D support. More recently, R&D spending has rebounded in several G-7 countries, as has R&D spending in the United States. Yet since annual R&D growth generally has been stronger in the United States than elsewhere and has even slowed to a standstill in Japan according to the most recently available statistics (see figure 4-27), the difference between the United States and the other G-7 countries' combined R&D spending has continued to widen.

Concurrent with the latest years' increase in the U.S. share of the G-7 countries' R&D performance, a similar increase has been seen in the U.S. share of all OECD countries' R&D spend-

[47]Most of the R&D data presented here are from reports to OECD, the most reliable source of such international comparisons. A high degree of consistency characterizes the R&D data reported by OECD, with differences in reporting practices among countries affecting their R&D/GDP ratios by no more than an estimated 0.1 percentage point (International Science Policy Foundation 1993). Nonetheless, an increasing number of non-OECD countries and organizations now collect and publish internationally comparable R&D statistics, which are reported at various points in this chapter.

[48]Current OECD members are Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, South Korea, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, Slovakia, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

[49]Although PPPs technically are not equivalent to R&D exchange rates, they better reflect differences in countries' research costs than do market exchange rates.

[50]Although countries other than members of the OECD also fund and perform R&D, with the exception of just a handful, most of these national R&D efforts are comparatively small. For example, in 1997 total R&D expenditures in China and Russia were $24.7 billion and $10.3 billion (PPP dollars) and nondefense R&D in Israel totaled $2.5 billion PPP (OECD 2000c). Among non-OECD members of Red Iberomericana de Indicadores de Ciencia y Tecnologia (RICYT), the largest R&D expenditures are reported for Brazil ($9.2 billion U.S. at market exchange rates), Argentina ($1.1 billion), Chile ($0.5 billion), and Colombia ($0.4 billion) (RICYT 2001). The combined R&D expenditures of these seven countries (approximately $50 billion) would raise the OECD world total by about 10 percent, and about one-half would be derived from China alone.

[51] OECD maintains R&D expenditure data that can be divided into three periods: (1) 1981 to the present, which are properly annotated and of good quality; (2) 1973 to 1980, which are probably of reasonable quality, for which some metadata are available; and (3) 1963 to 1972, about which there are serious doubts for most OECD countries (with notable exceptions of the United States and Japan), many of which launched their first serious R&D surveys in the mid-1960s. The analyses in this chapter are limited to data for 1981 and later years.

[52] The United Kingdom similarly experienced three years of declining real R&D expenditures, but its slump took place in 1995, 1996, and 1997. The falling R&D totals in Germany were partly a result of specific and intentional policies to eliminate redundant and inefficient R&D activities and to integrate the R&D efforts of the former East Germany and West Germany into a united German system.

Purchasing Power Parities: Preferred Exchange Rates for Converting International R&D Data

Comparisons of international R&D statistics are hampered because each country's R&D expenditures are denominated in its home currency. Two approaches are commonly used to normalize the data and facilitate aggregate R&D comparisons: dividing R&D by gross domestic product, which results in indicators of relative effort according to total economic activity and circumvents the problem of currency conversion, and converting all foreign-denominated expenditures to a single currency, which results in indicators of absolute effort. The first method is a straightforward calculation that permits only gross national comparisons. The second method permits absolute-level comparisons and analyses of countries' sector- and field-specific R&D investments, but it entails choosing an appropriate currency conversion series.

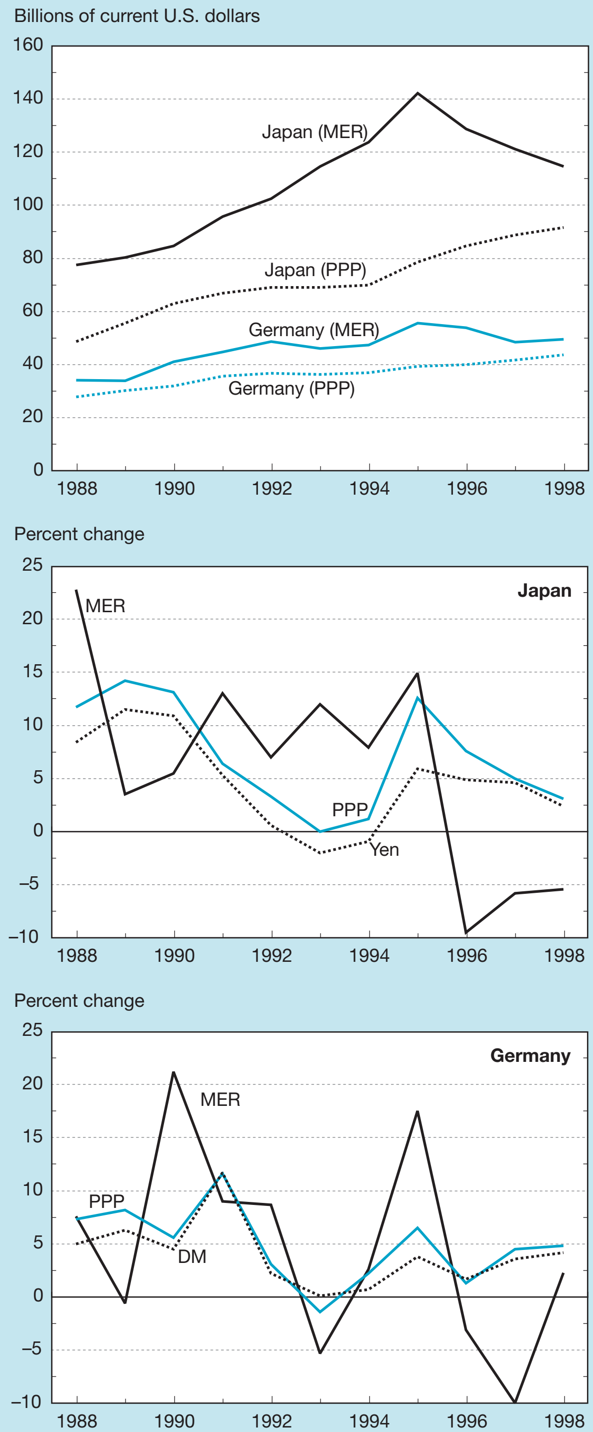
Market Exchange Rates Versus Purchasing Power Parity Rates

Because (for all practical purposes) no widely accepted R&D-specific exchange rates exist, the choice is between market exchange rates (MERs) (International Monetary Fund 1999) and purchasing power parities (PPPs) (OECD 2000a). These rates are the only series consistently compiled and available for a large number of countries over an extended period of time.

Market Exchange Rates—At their best, MERs represent the relative value of currencies for goods and services that are traded across borders; that is, MERs measure a currency's relative international buying power. Sizable portions of most countries' economies do not engage in international activity, however, and major fluctuations in MERs greatly reduce their statistical utility. MERs also are vulnerable to a number of distortions, including currency speculation, political events such as wars or boycotts, and official currency intervention, which have little or nothing to do with changes in the relative prices of internationally traded goods.

Purchasing Power Parity Rates—Because of the MER shortcomings described above, the alternative currency conversion series of PPPs has been developed (Ward 1985). PPPs take into account the cost differences across countries of buying a similar basket of goods and services in numerous expenditure categories, including nontradables. The PPP basket is, therefore, representative of total GDP across countries. When the PPP formula is applied to current R&D expenditures of other major performers, such as Japan and Germany, the result is a substantially lower estimate of total R&D spending than that given by MERs. (See figure 4-25.) For example, Japan's R&D in 1998 totaled $92 billion based on PPPs and $115 billion based on MERs, and the

Figure 4-25.
R&D expenditures and annual changes in R&D estimates, Japan and Germany



MER = market exchange rate; PPP = purchasing power parity; DM = deutsche mark

See appendix tables 4-2 and 4-40.

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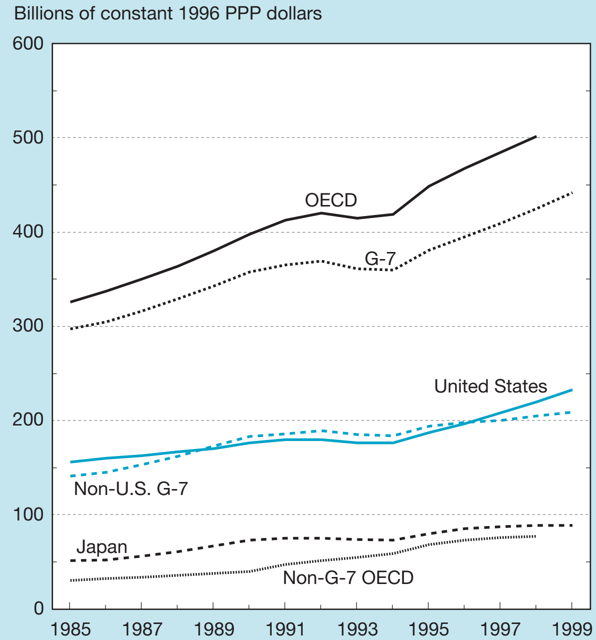
German R&D expenditure was $44 billion on PPPs and $50 billion on MERs. (By comparison, the U.S. R&D expenditure was $227 billion in 1998.)

PPPs are the preferred international standard for calculating cross-country R&D comparisons wherever possible and are used in all official OECD R&D tabulations. Unfortunately, they are not available for all countries and currencies. They are available for all OECD countries, however, and are therefore used in this report.

Exchange Rate Movement Effects

Although the difference is considerable between what is included in GDP-based PPP items and R&D expenditure items, the major components of R&D costs, fixed assets and the wages of scientists, engineers, and support personnel, are more suitable to a domestic converter than to one based on foreign trade flows. Exchange rate movements bear little relationship to changes in the cost of domestically performed R&D. (See figure 4-25.) When annual changes in Japan's and Germany's R&D expenditures are converted to U.S. dollars with PPPs, they move in tandem with such funding denominated in their home currencies. Changes in dollar-denominated R&D expenditures converted with MERs exhibit wild fluctuations that are unrelated to the R&D purchasing power of those investments. MER calculations indicate that, between 1988 and 1998, German and Japanese R&D expenditures each increased twice by 15 percent or more. In reality, nominal R&D growth was only one-fourth to one-third those rates in either country during this period. PPP conversions generally mirror the R&D changes denominated in these countries' home currencies.

Figure 4-26.
U.S., G-7, and OECD countries' R&D expenditures



OECD = Organisation for Economic Co-operation and Development; PPP = purchasing power parity

NOTE: Non-U.S. G-7 countries are Canada, France, Germany, Italy, Japan, and the United Kingdom.

See appendix table 4-40. *Science & Engineering Indicators – 2002*

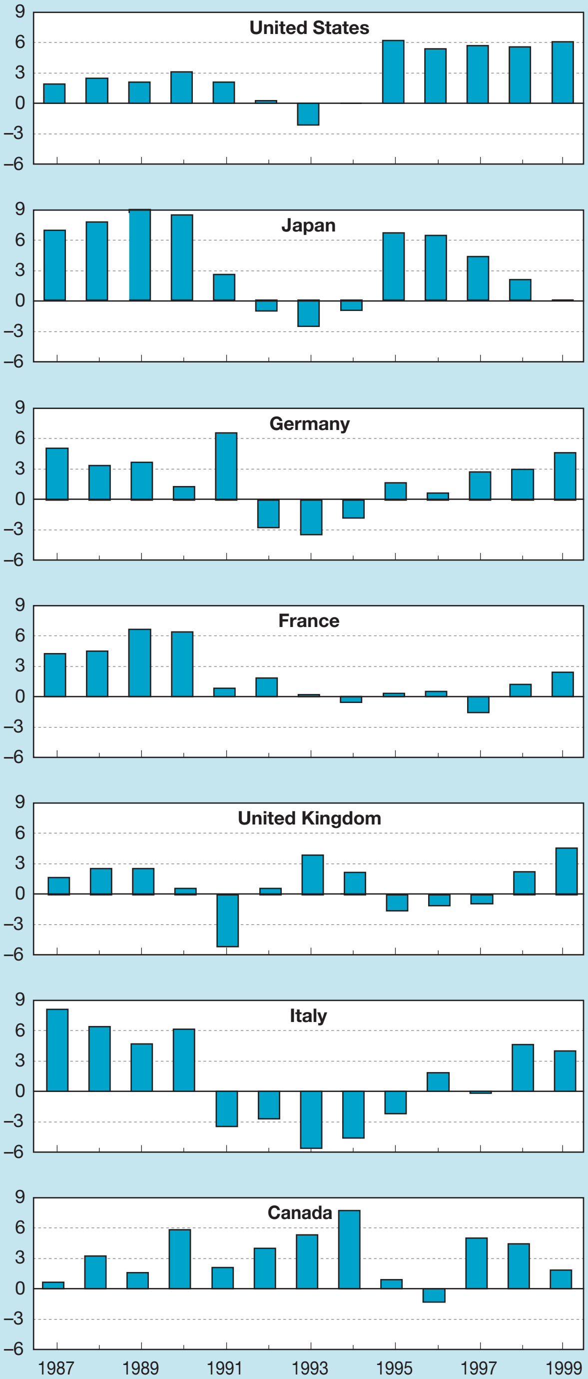
ing. In 1985, the United States accounted for 48 percent of the R&D reported by OECD countries; by 1995, the U.S. share had dropped to 42 percent of the OECD R&D total. Part of this share reduction (perhaps up to 2 percentage points) resulted from the addition of several countries to OECD membership (thereby increasing the OECD R&D totals); worldwide growth in R&D activities, however, was a greater contributing factor to the loss of R&D share experienced by the United States. Since then, the U.S. share has climbed back to 44 percent of the OECD total in 1999, more a result of robust R&D growth in the United States than a result of the significant changes under way in the other OECD countries.

Trends in Total R&D/GDP Ratios

One of the first (Steelman 1947) and now most widely used indicators of a country's commitment to growth in scientific knowledge and technology development is the ratio of R&D spending to GDP. (See figure 4-28.) For most of the G-8 countries (that is, the G-7 countries plus the Russian Federation), the latest R&D/GDP ratio is no higher now than it was at the start of the 1990s, which ushered in a period of slow growth or decline in their overall R&D efforts. The ways in which different countries have reached their current ratios vary considerably, however.[53] The United States and Japan reached 2.7 and 2.8 percent, respectively, in 1990–91. As a result of reduced or level spending by industry and government in both countries, the R&D/GDP ratios declined several tenths of a percentage point, to 2.4 and 2.6, respectively, in 1994 before rising again to 2.6 and 3.0 percent. Growth in industrial R&D accounted for much of the recovery in each of these countries. Electrical equipment, telecommunications, and computer services companies have reported some of the strongest R&D growth since 1995 in the United States. Growth in pharmaceutical R&D also has been substantial. In Japan, spending increases were highest in the electronics, machinery, and automotive sectors and appear to be associated mainly with a wave of new digital technologies (Industrial Research Institute 1999). However, the steady increase in Japan's R&D/GDP ratio since 1994 is also partially a result of anemic economic conditions overall: GDP fell in both 1998 and 1999,

[53] A country's R&D spending and therefore its R&D/GDP ratio is a function of several factors in addition to its commitment to supporting the R&D enterprise. Especially because the majority of R&D is performed by industry in each of these countries, the structure of industrial activity can be a major determinant of a country's R&D/GDP ratio. For example, economies with high concentrations in manufacturing (which traditionally have been more R&D intensive than nonmanufacturing or agricultural economies) have different patterns of R&D spending. See "Industry Sector" for further discussion of such considerations.

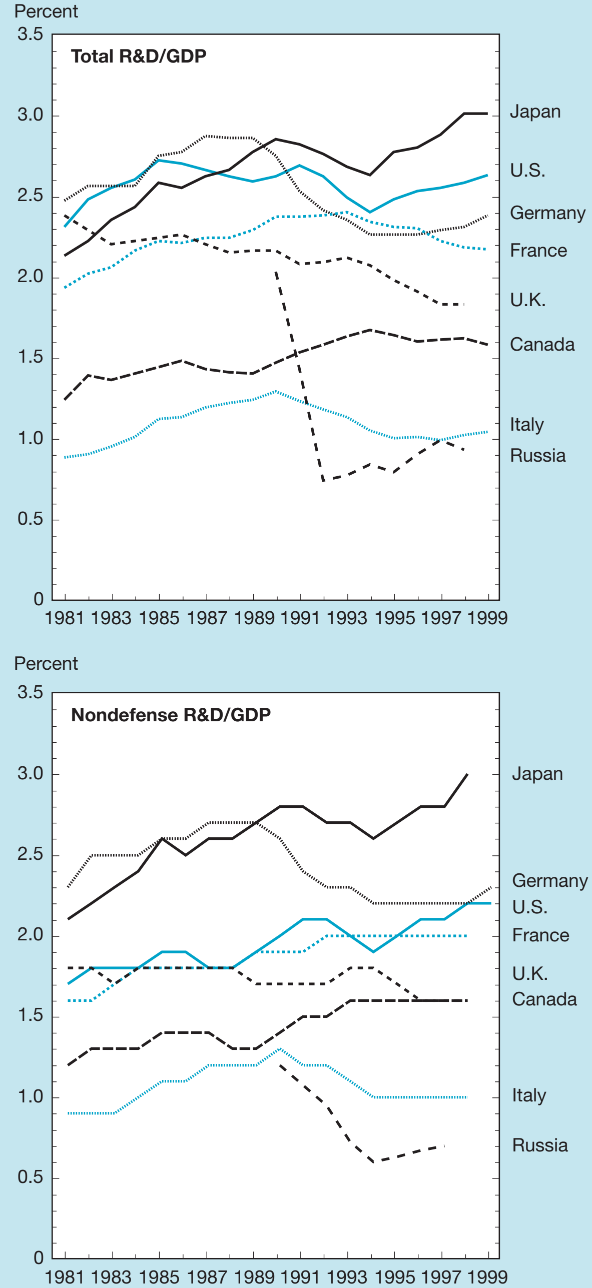
Figure 4-27.
Rates of change in total inflation-adjusted R&D spending



NOTE: The inflation-adjusted R&D expenditures reflected in this graph are denominated in foreign currencies deflated by the countries' own GDP price deflators and therefore are not distorted by exchange rate conversions.

See appendix table 4-40. *Science & Engineering Indicators – 2002*

Figure 4-28.
R&D as percentage of GDP, G-8 countries



See appendix tables 4-40 and 4-41.

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so that even level R&D spending resulted in a slight increase in its R&D ratio (OECD 2000a).

Among the remaining six G-8 countries, two (Germany and Russia) display recent increases in their economies' R&D intensity, and four (the United Kingdom, France, Italy, and Canada) report an R&D/GDP ratio that has remained stagnant or continues to decline. In Germany, the R&D/GDP ratio fell from 2.9 percent at the end of the 1980s, before reunification, to 2.3 percent in 1993 before rising to its current level of 2.4 percent. By comparison, this macro-R&D

indicator continues to slip slightly in France and the United Kingdom to their current levels of 2.2 and 1.9 percent, respectively, and has fluctuated narrowly at 1.0 and 1.6 percent in Italy and Canada, respectively, for the past five years or longer. The end of the cold war and collapse of the Soviet Union had a drastic effect on Russia's R&D enterprise. R&D spending in Russia was estimated at 2.0 percent of GDP in 1990; that figure plummeted to 1.4 percent in 1991 and then tumbled further to 0.7 percent in 1992. Moreover, the severity of this R&D decline is masked somewhat: although the R&D share was falling, it also was a declining share of a declining GDP. By 1999, the R&D/GDP ratio in Russia had inched back to about 1.0 percent, although the country continues to experience severe reductions in its R&D spending.

Overall, the United States ranked fifth among OECD countries in terms of reported R&D/GDP ratios for the 1996–99 period. (See text table 4-13.) Sweden leads all countries with 3.7 percent of its GDP devoted to R&D, followed by Japan (3.0 percent), Finland (2.9 percent), and Switzerland (2.7 percent). In general, nations in Southern and Eastern Europe tend to have R&D/GDP ratios below 1.5 percent, whereas Nordic nations and those in Western Europe report R&D spending shares greater than 1.5 percent. In a broad sense, the reason for such patterns has much to do with overall funding patterns and macroeconomic structures. In practically all OECD countries, the business sector finances most of the R&D. However, OECD countries with relatively low R&D/GDP ratios tend to be relatively low-income countries, and government funding tends to provide a larger proportion of the R&D support than it provides in the high R&D/GDP ratio countries. Furthermore, the private sector in such low-income countries often consists of low-technology industries, resulting in low overall R&D spending and, therefore, low R&D/GDP ratios. Indeed, a strong link exists between countries with high incomes that emphasize the production of high-technology goods and services and those that invest heavily in R&D activities (OECD 2000e).[54]

Text table 4-13.
R&D percentage of gross domestic product

Sweden (1997)	3.70	Brazil (1996)	0.91
Japan (1999)	3.01	Spain (1999)	0.89
Finland (1998)	2.89	Slovak Republic (1998)	0.86
Switzerland (1996)	2.73	Cuba (1999)	0.83
United States (1999)	2.63	Poland (1999)	0.75
South Korea (1998)	2.55	China (1998)	0.69
Israel (1997)	2.54	South Africa (1998)	0.69
Germany (1999)	2.38	Hungary (1999)	0.68
France (1999)	2.17	Chile (1997)	0.63
Denmark (1999)	1.99	Portugal (1997)	0.62
Belgium (1999)	1.98	Romania (1998)	0.54
Taiwan (1998)	1.97	Greece (1997)	0.51
Netherlands (1998)	1.95	Turkey (1997)	0.49
Iceland (1999)	1.88	Argentina (1999)	0.47
United Kingdom (1999)	1.87	Colombia (1997)	0.41
Canada (1999)	1.85	Mexico (1997)	0.34
Austria (1999)	1.82	Panama (1998)	0.33
Norway (1999)	1.73	Bolivia (1999)	0.29
Australia (1998)	1.49	Uruguay (1999)	0.26
Singapore (1997)	1.47	Malaysia (1996)	0.22
Slovenia (1997)	1.42	Trinidad and Tobago (1997)	0.14
Ireland (1997)	1.39	Nicaragua (1997)	0.13
Czech Republic (1999)	1.27	Ecuador (1998)	0.08
Costa Rica (1996)	1.13	El Salvador (1998)	0.08
New Zealand (1997)	1.13	Peru (1997)	0.06
Italy (1999)	1.04	**Total OECD** (1998)	2.18
Russian Federation (1999)	1.06	**European Union** (1998)	1.81

NOTES: Civilian R&D only for Israel and Taiwan. Data are presented for the latest available year in parentheses.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (April 2001); Pacific and Economic Cooperation Council (1999); OECD, *R&D Efforts in China, Israel, and Russia: Some Comparisons With OECD Countries,* (CCNM/DSTI/EAS, Paris, 2000); Centre for Science Research and Statistics (CSRS), *Russian Science and Technology at a Glance: 2000* (Moscow 2001); Red Iberomericana de Indicadores de Ciencia y Tecnologia (Iberomerican Network of Science & Technology Indicators) (RICYT), *Principales Indicadores de Ciencia y Tecnologia 2000* (Buenos Aires, Argentina 2001); and national sources.

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Outside the European region, R&D spending has intensified considerably since the early 1990s. Several Asian countries, most notably South Korea and China, have been particularly aggressive in expanding their support for R&D and S&T-based development. In Latin America and the Pacific region, other non-OECD countries also have attempted to increase R&D investments substantially during the past several years. Even with recent gains, however, most non-European (non-OECD) countries invest a smaller share of their economic output on R&D than do OECD members (with the exception of Israel, whose reported 2.5 percent nondefense R&D/GDP ratio ranks seventh in the world). With the apparent exception of Costa Rica, all Latin American countries for which such data are available report R&D/GDP ratios below 1 percent. (See text table 4-13.) This distribution is consistent with broader indicators of economic growth and wealth. However, many of these countries also report additional S&T-related expenditures on human resources training and S&T infrastructure development that are not captured in R&D and R&D/GDP data (Red Iberomericana de Indicadores de Ciencia y Tecnologia 2001).

Nondefense R&D Expenditures and R&D/GDP Ratios

As a result of concerns related to national scientific progress, standard-of-living improvements, economic competitiveness, and commercialization of research results, attention has shifted from nations' total R&D activities to nondefense R&D expenditures as indicators of scientific and technological strength. Indeed, conclusions about a country's relative standing may differ dramatically, depending on whether total R&D expenditures are considered or defense-related expenditures are excluded from the totals; for some countries, the relative emphasis has shifted over time. Among

[54] See OECD (1999b) for further discussion of these and other broad R&D indicators for OECD countries.

G-8 countries, the inclusion of defense R&D has little impact on R&D totals for Japan, Germany, Italy, and Canada, where defense R&D represents 5 percent or less of the national total. In other countries, defense has accounted for a more significant, although since the end of the cold war declining, proportion of the national R&D effort. Between 1988 and 1998, the defense share of the R&D total:

- has fallen from 31 to 15 percent in the United States,
- has fallen from 21 to 7 percent in France,
- has fallen from 17 to 12 percent in the United Kingdom, and
- accounts for approximately 25 percent of the 1998 Russian R&D total.

Consequently, if current trends persist, the distinction between defense and nondefense R&D expenditures in international comparisons may become less important. In absolute dollar terms, the U.S. nondefense R&D spending is still considerably larger than that of its foreign counterparts. In 1998 (the latest year for which comparable international R&D data are available from most OECD countries), U.S. nondefense R&D was more than twice that of Japan and was equivalent to 94 percent of the non-U.S. G-7 countries' combined nondefense R&D total. (See appendix table 4-41.)

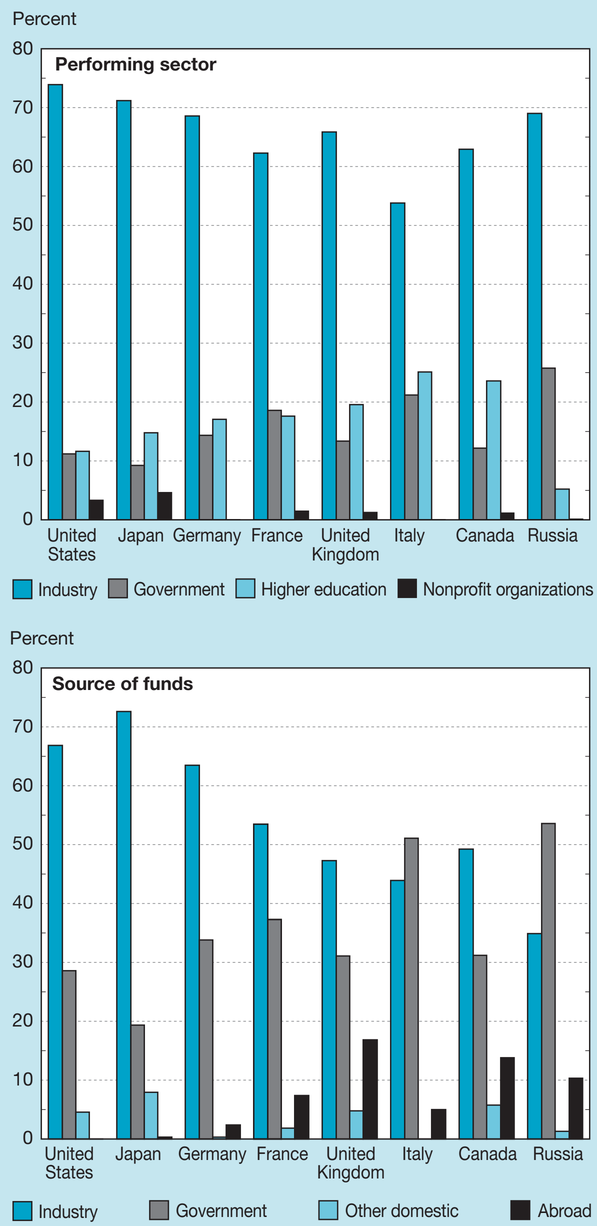
In terms of R&D/GDP ratios, the relative position of the United States is somewhat less favorable for this nondefense metric compared with those ratios for all R&D combined. Japan's nondefense R&D/GDP ratio (3.0 percent) exceeded that of the United States (2.2 percent) in 1998, as it has for years. (See figure 4-28 and appendix table 4-41.) The nondefense R&D ratio of Germany (2.3 percent in 1999) slightly exceeded that of the United States (again, in contrast to total R&D). The 1998 nondefense ratio for France (2.0 percent) was slightly below the U.S. ratio; ratios for the United Kingdom and Canada (each at 1.6 percent) and for Italy (1.0 percent) were considerably lower. The nondefense R&D/GDP ratio for Russia was nearly one-third (0.7 percent) the U.S. ratio.

International R&D by Performer, Source, and Character of Work

Broad Sector Patterns

Although marked differences are observed in the financing and performance of R&D among both OECD and non-OECD countries, similarities also are observed in R&D patterns for the G-8 countries. Government and industry account for roughly 80 percent or more of the R&D funding in each of these eight countries, although the respective contributions vary substantially across countries.[55] The industrial sector provided more than 70 percent of R&D funds in Japan, 67 percent in the United States, 64 percent in Germany, 54 percent in France; and between 44 and 49 percent in the United Kingdom, Italy, and Canada. (See figure 4-29.) In Russia, industry provided approximately 35 percent of the nation's R&D funding. Government provided the largest share (54 percent) of Russia's R&D total, as it did in Italy (at 51 percent of the national R&D effort). In the remaining six countries, government was the second largest source of R&D funding, ranging between 19 percent (in Japan) and 37 percent (in France) of the total. In each of these eight countries, government provided the largest share of the funds used for academic R&D performance. (See appendix table 4-42.)

Figure 4-29.
R&D expenditures by performer and source, G-8 countries



NOTES: Japan, France, United Kingdom, and Russia data for 1998. U.S., Germany, Italy, and Canada data for 1999.

See appendix table 4-42. *Science & Engineering Indicators – 2002*

[55] In accordance with international standards, sources of funding are attributed to the following sectors: all levels of government combined, business enterprises, higher education, private nonprofit organizations, and funds from abroad. The taxonomy used in presenting U.S. R&D expenditures elsewhere in this chapter differs somewhat.

The industrial sector dominates R&D performance in each of the G-8 countries. (See figure 4-29.) Industry performance shares for the 1998–99 period ranged from a little more than 70 percent in the United States and Japan to less than 54 percent in Italy. Industry's share was between 62 and 69 percent in France, Canada, the United Kingdom, Germany, and Russia. Most of the industrial R&D performance in these countries was funded by industry. Government's share of funding for industry R&D performance ranged from as little as 2 percent in Japan to 43 percent in Russia. (See appendix table 4-42.) In the other G-8 countries, the government funding share of industrial R&D ranged narrowly between 5 and 13 percent.

In most of these countries, the academic sector was the next largest R&D performer (at about 12 to 25 percent of the performance total in each country).[56] Academia often is the primary location of research (as opposed to R&D) activities, however. Government was the second largest R&D performing sector in France (which included spending in some sizable government laboratories), as it was in Russia (accounting for 26 percent of that nation's R&D effort).

[56] The national totals for Europe, Canada, and Japan include the research component of general university fund (GUF) block grants (not to be confused with basic research) provided by all levels of government to the academic sector. Therefore, at least conceptually, the totals include academia's separately budgeted research and research undertaken as part of university departmental R&D activities. In the United States, the Federal Government generally does not provide research support through a GUF equivalent, preferring instead to support specific, separately budgeted R&D projects. On the other hand, a fair amount of state government funding probably does support departmental research at public universities in the United States. Data on departmental research, considered an integral part of instructional programs, generally are not maintained by universities. U.S. totals are most certainly underestimated relative to the R&D effort reported for other countries.

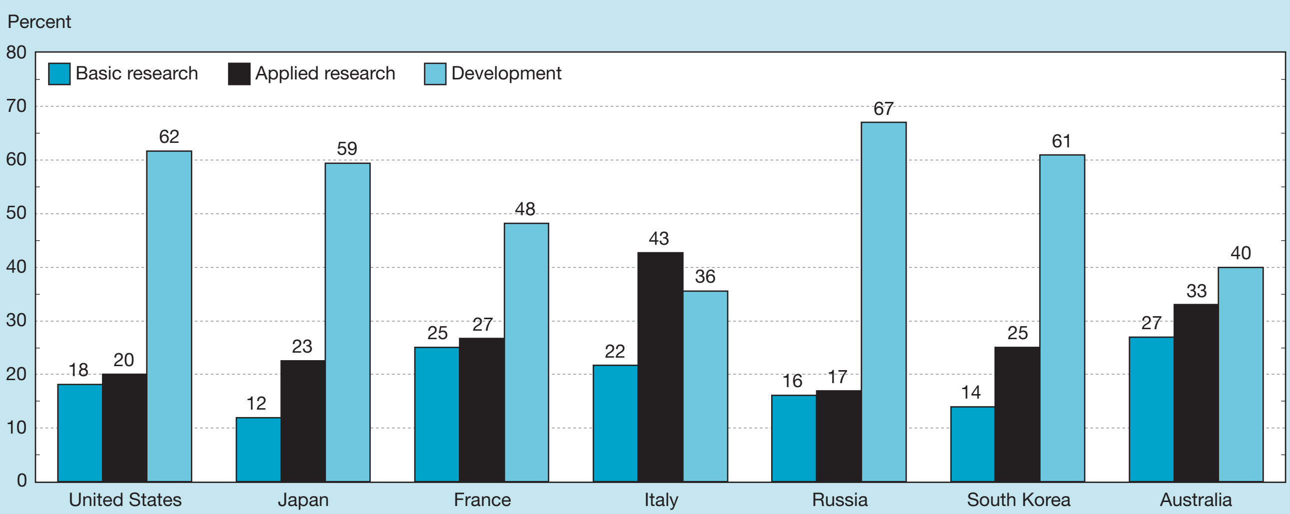
Character of R&D Effort

Not all of the G-8 countries categorize their R&D expenditures into basic research, applied research, or development categories, and for several countries that do use this taxonomy, the data are somewhat dated (OECD 2000b). In fact, only 6 of the 30 OECD members (and Russia) have reported their countries' character of work shares for 1998 or later. R&D classification by character of work probably involves a greater element of subjective assessment than other R&D indicators. See sidebar, "Choice of the 'Right' R&D Taxonomy Is a Historical Concern." Rather than resulting from surveys, the data often are estimated in large part by national authorities.[57] Nonetheless, where these data exist, they indicate the relative emphasis that a country places on supporting fundamental scientific activities—the seed corn of economic growth and technological advancement.

The United States expends approximately 18 percent of its R&D on activities that performers classify as basic research. (See figure 4-30.) About one-half of this research is funded by the Federal Government and performed in the academic sector. The largest share of this basic research effort is conducted in support of life sciences. Basic research accounts for comparatively smaller amounts of the national R&D per-

[57] The magnitude of the amounts estimated as basic research also is affected by how R&D expenditures are themselves estimated by national authorities. International R&D survey standards recommend that both capital and current expenditures be included in the R&D estimates, including amounts expended on basic research. Each of the non-U.S. countries displayed in figure 4-30 includes capital expenditures on fixed assets at the time they took place (OECD 1999b). All U.S. R&D data reported in the figure include depreciation charges instead of capital expenditures. U.S. R&D plant data (not shown in the figure) are distinct from current fund expenditures on R&D.

Figure 4-30.
Distribution of R&D expenditures by character of work in selected countries: 1998



NOTES: The character of work for 6 percent of Japan's R&D is unknown. Details may not sum to total because of rounding.

SOURCES: Organisation for Economic Co-operation and Development (OECD), 2000b; Centre for Science Research and Statistics (CSRS), 2001.

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Choice of the "Right" R&D Taxonomy Is a Historical Concern

With the following words, written more than 50 years ago, Vannevar Bush (1945) laid the basis in his seminal report, *Science—The Endless Frontier,* for what eventually became known (and perhaps was unfairly derided) as the linear model of innovation:

"Scientific research may be divided into the following broad categories: (1) pure research, (2) background research, and (3) applied research and development. The boundaries between these categories are by no means clear-cut and it is frequently difficult to assign a given investigation to any single category. On the other hand, typical instances are easily recognized, and study reveals that each category requires different institutional arrangements for maximum development." (p. 81.)… "Basic research…creates the fund from which the practical applications of knowledge must be drawn. New products and new processes do not appear full-grown. They are founded on new principles and new conceptions, which in turn are painstakingly developed by research in the purest realms of science." (p. 19.)

Bush's model somewhat simplistically depicts innovation as a three-step process whereby (1) scientific breakthroughs from the performance of basic research (2) lead to applied research, which (3) leads to the development or application of applied research to commercial products, processes, and services. Although it is quite unlikely that either scientific or statistical experts ever really believed that such a model captured the complex relationships between science, technology, and innovation, it did (and still does) lend itself to the collection and analysis of data for policymaking purposes.

Most of the criticism surrounding the inappropriateness of the basic research, applied research, and development categories that are used in practically all R&D data collection efforts (see sidebar, "Definitions of Research and Development," at the beginning of this chapter) focus on the lack of clear boundaries between basic research and applied research.[*] This debate took form ever since Bush first differentiated "basic research" (a term he used interchangeably with "pure research") as that which is performed without thought of specific practical ends from applied research, the function of which is to provide "complete answers" to practical problems. A number of proposals have arisen over the years to replace, or supplement, the basic/applied research taxonomic categories, including fundamental versus strategic research, exploratory versus programmatic research, curiosity-driven versus mission-oriented research—to name just a few.[†]

Indeed, in the last published version (OECD 1994) of the *Frascati Manual* (international standards and guidelines for conducting R&D surveys), the option of collecting separate data on "pure basic research" and "oriented basic research" was introduced. To date, few countries have chosen to collect research expenditure data with these, or similar, reporting refinements. More generally, none of the proposed alternatives has gained a consensus in either the scientific, political, or statistical communities; each proposed alternative suffers from its own shortcomings which are as least as problematic as the taxonomic categories that would be replaced. On a more historical note, Bush himself was not particularly concerned about the precision of the definitions he used. Rather, he simply wanted to establish a framework that offered the best chance for basic research to receive special protection and, more important, ensured government financial support.

[*]It is just as likely, however, that the distinctions between applied research and development and between development and related (for example, routine testing and evaluation) and downstream (for example, preproduction) activities are subject to their own reporting complexities.

[†]One of the more recent well-known alternative taxonomy paradigms was developed by the late David Stokes (1997) and depicted in *Pasteur's Quadrant: Basic Science and Technological Innovation*. Stokes suggested multiple research categories: pure basic research (work inspired by the quest for basic understanding but not by potential use), purely applied research (work motivated only by potential use), and strategic research (work inspired by both potential use and fundamental understanding). Stokes characterized Louis Pasteur's research on the microbiological process of disease in the late 19th century as strategic research.

formance efforts in the Russian Federation (16 percent); South Korea (14 percent), which is currently the sixth largest R&D-performing member of OECD; and Japan (12 percent). Compared with patterns in the United States, however, a considerably greater share is funded for engineering research activities in each of these three countries. Conversely, basic research accounts for more than 20 percent of total R&D performance reported in Italy, France, and Australia.[58]

In contrast to spending patterns reported for most countries, spending on applied research activities accounts for the largest proportion (43 percent) of Italy's R&D total. In each of the other countries shown here, development accounted for the largest share of national totals (approximately 60 percent but as little as 40 percent of total in Australia), with most of the experimental development work under way in their respective industrial sectors.

Higher Education Sector

Source of Funds. In many OECD countries, the academic sector is a distant second to industry in terms of the national R&D performance effort. Among G-8 countries, universities

[58]The most current character of work data available from OECD sources for Germany are for 1993. The United Kingdom compiles such data only for the industry and government sectors, not for higher education or its nonprofit sector, the traditional locus of basic research activities.

account for as little as 5 percent of Russia's R&D total to upward of a 25 percent share in Italy.[59] For most of these countries, the government is now, and historically has been, the largest source of academic research funding. However, in each of these countries for which historical data exist (the exception being Russia), the government financing share has declined during the past 20 years, and industry as a source of university R&D funding has increased. Specifically, the government share, including both direct government support for academic R&D and the R&D component of block grants to universities,[60] has fallen by 8 percentage points or more in six of the G-7 countries since 1981 (the exception being Italy, in which the government share has dipped from 96 to 94 percent of the academic R&D total). By comparison, and as an indication of an overall pattern of increased university-firm interactions (often intending to promote the commercialization of university research), the funding proportion from industry sources for these seven countries combined climbed from 2.5 percent of the academic R&D total in 1981, to 5.4 percent in 1990, to 6.4 percent in 1998. In Germany and Canada, almost 11 percent of university research is now funded by industry. (See text table 4-14.)

S&E Fields. As noted in the discussion on the character of the R&D effort, the national emphases in particular S&E fields differ across countries. Where they are collected at all, most of the internationally comparable data on field-specific R&D are reported for the higher education sector. Although difficult to generalize, it would appear that most countries supporting a substantial level of academic R&D (defined at $1 billion PPPs in 1998) devote a relatively larger proportion of their R&D for engineering, social sciences, and humanities than does the United States. (See text table 4-15.) Conversely, the U.S. academic R&D effort emphasizes the medical sciences and natural sciences relatively more than do many other OECD countries.[61] The latter observation is consistent with the overall U.S. relative R&D emphases in health and biomedical sciences for which NIH and U.S. pharmaceutical companies are known.

Text table 4-14.
Academic R&D expenditures, by country and source of funds
(Percentages)

Country and source of funds	1981	1990	1999
Canada			
Government	79.8	73.2	66.4
Other	16.4	20.9	22.8
Industry	3.9	5.9	10.8
France			
Government	97.7	92.9	88.9
Other	1.0	2.2	7.7
Industry	1.3	4.9	3.4
Germany			
Government	98.2	92.1	87.5
Other	0.0	0.0	2.0
Industry	1.8	7.9	10.6
Italy			
Government	96.2	96.7	94.4
Other	1.1	0.9	0.9
Industry	2.7	2.4	4.8
Japan			
Government	57.7	51.2	49.1
Other	41.3	46.5	48.5
Industry	1.0	2.3	2.3
United Kingdom			
Government	81.3	73.5	64.4
Other	15.9	19.0	28.3
Industry	2.8	7.6	7.3
United States			
Government	74.1	66.9	65.6
Other	21.5	26.2	26.9
Industry	4.4	6.9	7.3

NOTES: Canada data are for 1983; France, Japan, and United Kingdom data are for 1998.

SOURCE: Organisation for Economic Co-operation and Development (OECD), *Basic Science and Technology Statistics* (Paris, March 2000).

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Industry Sector

Sector Focus. Industrial firms account for the largest share of the total R&D performance in each of the G-8 countries. However, the purposes to which the R&D is applied differ somewhat, depending on the overall industrial composition of the economy. Furthermore, the structure of industrial activity can itself be a major determinant of the level and change in a country's industrial R&D spending. Variations in such spending can result from differences in absolute output, industrial structure, and R&D intensity. Countries with the same size economy could have vastly different R&D expenditure levels (and R&D/GDP ratios). Differences might depend on the share of industrial output in the economy, on whether the industries that account for the industrial output are traditional

[59]Country data are for 1998 or 1999. (See appendix table 4-42.)

[60]Whereas GUF block grants are reported separately for Japan, Canada, and European countries, the United States does not have an equivalent GUF category. In the U.S., funds to the university sector are distributed to address the objectives of the Federal agencies that provide the R&D funds. Nor is GUF equivalent to basic research. The treatment of GUF is one of the major areas of difficulty in making international R&D comparisons. In many countries, governments support academic research primarily through large block grants that are used at the discretion of each individual higher education institution to cover administrative, teaching, and research costs. Only the R&D component of GUF is included in national R&D statistics, but problems arise in identifying the amount of the R&D component and the objective of the research. Government GUF support is in addition to support provided in the form of earmarked, directed, or project-specific grants and contracts (funds for which can be assigned to specific socioeconomic categories). In the United States, the Federal Government (although not necessarily state governments) is much more directly involved in choosing which academic research projects are supported than are national governments in Europe and elsewhere. In each of the European G-7 countries, GUF accounts for 50 percent or more of total government R&D to universities and for roughly 40 percent of the Canadian government academic R&D support. Thus, these data indicate not only relative international funding priorities but also funding mechanisms and philosophies regarding the best methods for financing research.

[61]In international S&E field compilations, the natural sciences comprise math and computer sciences, physical sciences, environmental sciences, and all life sciences other than medical and agricultural sciences. Also note that the U.S. academic R&D effort is considerably larger than in any other country and the U.S. total ($25 billion PPP) is comparable with the combined R&D total ($29 billion PPP) of the other seven countries listed in text table 4-15.

Text table 4-15.
Shares of academic R&D expenditures, by country and S&E field: 1998
(Percentages)

Field	United States	Japan	Germany	Australia	South Korea	Spain	Sweden	Russia
Total academic R&D (billions of 1995 PPP dollars)	24.8	13.4	7.3	2.0	1.8	1.8	1.4	1.4
Percent of total academic R&D								
Natural science and engineering	92.7	66.1	78.5	73.0	91.5	77.9	81.7	88.3
Natural sciences	41.0	11.5	30.3	27.5	18.5	40.8	22.3	59.0
Engineering	15.6	24.4	20.5	16.2	49.0	18.0	23.6	26.7
Medical sciences	28.6	25.5	23.3	22.8	17.0	13.9	29.0	1.7
Agricultural sciences	7.6	4.6	4.4	6.6	7.0	5.2	6.7	0.9
Social sciences and humanities	7.3	33.9	21.5	27.0	8.5	22.1	18.3	11.7
Social sciences	6.0	NA	8.6	19.5	NA	14.2	12.2	6.6
Humanities	1.3	NA	12.9	7.6	NA	7.8	6.1	5.1
Percent of academic NS&E R&D								
Natural science and engineering	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Natural sciences	44.2	17.4	38.6	37.7	20.2	52.4	27.3	66.8
Engineering	16.8	37.0	26.1	22.1	53.6	23.1	28.9	30.2
Medical sciences	30.8	38.6	29.6	31.2	18.6	17.8	35.5	1.9
Agricultural sciences	8.2	7.0	5.6	9.0	7.6	6.6	8.3	1.1

PPP = purchasing power parity; NA = detail not available, but included in totals

NOTES: These are the only OECD countries that report more than $1 billion (1995 PPPs) in higher education R&D and that provide S&E field data. Data for Sweden are for 1997.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (April 2001); Centre for Science Research and Statistics (CSRS), *Russian Science and Technology at a Glance: 2000* (Moscow, 2001); and National Science Foundation, Division of Science Resources Statistics (NSF/SRS).

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sites of R&D activity (e.g., food processing firms generally conduct less R&D than pharmaceutical firms), and on whether individual firms in the same industries devote substantial resources to R&D or emphasize other activities (i.e., firm-specific intensities). Text table 4-16 provides the distribution of industrial R&D performance in the G-8 countries and in Sweden and Finland, which have the first and third highest R&D/GDP ratios in the world, respectively.[62]

The level of industrial R&D in the United States far exceeds the level reported for any and all other of these countries, and therefore, the data are reported as shares of countries' industrial R&D totals. Most of these countries perform R&D in support of a large number of industry sectors. The sector distribution of the U.S. industrial R&D effort, however, is among the most widespread and diverse. This perhaps indicates a national inclination and ability to invest in becoming globally competitive in numerous industries rather than specializing in just a few industries or niche technologies. No U.S. industry sector accounts for more than 13 percent of the industry R&D total (the electrical equipment industry representing the highest level), and only two others (office machinery, including computers, and aerospace) account for 10 percent or more of the industry total. By comparison, most of the other countries display somewhat higher sector concentrations, including 20 percent or higher industry R&D shares for electrical equipment firms in Finland (at 44 percent of its industry total), Canada, Italy, and Sweden. Indeed, the electrical equipment sector is among the largest performers of the industrial R&D effort in 8 of the 10 countries shown (exceptions are the United Kingdom and Russia). Among other manufacturing sectors, 20 percent or higher shares are reported for motor vehicles in Germany and for pharmaceuticals in the United Kingdom, which is consistent with general economic production patterns.[63]

As indicated earlier, one of the more significant trends in U.S. industrial R&D activity has been the growth of the R&D effort within the nonmanufacturing sector. According to the internationally harmonized data in text table 4-16, such growth accounted for 20 percent of the U.S. 1997 industry R&D total, with computer services, R&D services, and trade each accounting for the largest individual shares (about 5 percent). A number of other countries also report substantial increases in their service sector R&D expenditures during the past 25 years. Among G-7 countries, nonmanufacturing R&D shares have increased by about 5 percentage points in France and Italy and by 13 percentage points in the United States, United Kingdom, and Canada since the early 1980s (Jankowski 2001b). In each of these three English-speaking countries, computer and related services account for a substantial share of the service R&D totals. Furthermore, R&D services appear to be an important locus of industry activity in several countries, reflecting in part the growth in outsourcing and

[62] Similar industrial R&D details for Switzerland and South Korea (which report the fourth and sixth highest R&D/GDP ratios in the world, respectively) were not available from OECD harmonized databases (OECD 2000a).

[63] See OECD (1999a) for a harmonized historical series on industry R&D expenditures in several OECD countries.

Text table 4-16.
Shares of industrial R&D, by industry sector for selected countries
(Percentages)

Industry	United States (1997)	Canada (1998)	Germany (1997)	France (1997)	Italy (1998)	Japan (1997)	United Kingdom (1998)	Russian Federation (1997)	Sweden (1997)	Finland (1998)
Total (billions of PPP dollars)	157.5	7.6	28.2	16.6	6.7	66.1	15.5	5.7	5.1	2.2
Percent of total										
Total business enterprise	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total manufacturing	79.9	63.8	93.5	87.3	85.6	92.6	80.5	36.8	85.9	87.2
Food, beverages, and tobacco	1.2	1.1	0.7	1.8	1.3	2.5	2.4	0.1	1.0	2.1
Textiles, fur, and leather	0.3	0.7	0.7	0.6	0.4	0.7	0.3	0.1	0.1	0.6
Wood, paper, printing, and publishing	1.4	1.6	0.4	0.4	0.3	1.1	0.5	0.2	3.4	4.2
Coke, ref. petroleum products, and nuclear fuel	1.1	1.2	0.3	1.4	0.6	0.6	3.5	0.5	0.2	0.6
Chemicals (less pharmaceuticals)	4.6	2.3	12.2	6.3	5.5	8.9	6.7	1.8	1.3	4.3
Pharmaceuticals	7.6	6.8	6.5	12.8	8.3	5.9	21.9	0.2	15.2	3.4
Rubber and plastic products	0.9	0.6	1.7	2.7	1.8	2.4	0.6	0.3	0.9	2.1
Nonmetallic mineral products	0.4	0.1	0.9	1.2	0.3	2.0	0.5	0.2	0.5	0.8
Basic metals	0.6	1.8	1.0	1.7	1.1	3.5	0.7	1.1	1.0	1.2
Fabricated metal products	1.2	1.0	1.5	1.2	4.4	1.2	0.9	0.2	1.1	1.9
Machinery, NEC	3.7	2.2	11.0	4.5	5.7	8.6	6.3	11.9	9.8	10.4
Office, accounting and computing machinery	11.6	4.0	2.3	2.4	1.8	9.7	1.2	0.0	0.8	0.7
Electrical machinery	2.9	0.9	3.0	3.6	5.5	10.5	4.1	1.3	1.5	5.2
Electronic equipment (radio, TV, and communications)	13.0	25.1	11.3	11.8	19.9	16.3	7.5	3.2	21.9	43.6
Instruments, watches, and clocks	8.8	1.2	5.2	9.9	1.7	3.9	3.3	0.8	5.2	3.5
Motor vehicles	9.6	1.6	24.2	12.1	15.3	12.8	8.9	3.2	18.2	0.5
Other transport equipment (less aerospace)	0.3	0.1	1.6	0.6	1.5	0.4	0.7	3.0	0.5	1.5
Aerospace	10.3	10.8	8.5	11.5	9.9	1.0	10.2	8.7	3.1	0.0
Furniture, other manufacturing NEC	NA	0.7	0.5	0.6	0.4	0.8	0.2	0.0	0.2	0.6
Recycling	0.3	NA	0.0	0.0	0.0	NA	0.0	0.0	NA	0.1
Electricity, gas, and water	0.2	2.7	0.3	3.0	1.7	0.9	1.4	0.5	0.8	1.6
Construction	0.2	0.3	0.3	1.0	0.3	2.1	0.4	0.9	0.6	0.8
Agriculture and mining	0.1	2.9	0.5	1.8	0.0	0.0	1.4	3.3	1.1	0.7
Total services	19.7	30.3	5.4	7.0	12.3	4.4	16.4	58.5	11.6	9.8
Wholesale, retail trade, motor vehicle repair, etc.	5.2	7.2	0.1	NA	0.4	NA	0.1	0.0	NA	0.1
Hotels and restaurants	0.1	NA	NA	NA	0.0	NA	NA	0.0	NA	NA
Transport and storage	0.4	0.1	0.2	2.8	0.1	0.1	0.2	0.5	0.3	0.2
Communications	1.3	1.3	NA	NA	0.7	2.7	4.4	0.7	2.3	5.4
Financial intermediation (incl. insur.)	1.0	2.8	0.0	NA	0.8	NA	NA	0.0	NA	NA
Computer and related activities	5.6	6.9	1.7	2.4	2.2	1.6	6.7	1.1	3.2	3.0
Research and development	4.5	9.5	1.4	NA	5.8	NA	3.4	44.9	5.2	NA
Other business activities NEC	NA	2.5	1.4	1.8	2.0	NA	1.5	0.4	0.5	0.8
Community, social and personal service activities, etc.	NA	NA	0.1	NA	0.2	NA	0.1	10.9	0.1	0.3

PPP = purchasing power parity; NA = not available separately; NEC = not elsewhere classified

NOTE: Analytical Business Enterprise Research and Development (ANBERD) data not available for Switzerland and South Korea. Data are for the years listed under country names.

SOURCES: Organisation for Economic Co-operation and Development (OECD), Analytical Business Enterprise Research and Development (ANBERD) database (DSTI/EAS Division), (Paris, 2000); and OECD, *R&D Efforts in China, Israel, and Russia: Some Comparisons With OECD Countries* (CCNM/DSTI/EAS, Paris, 2000).

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greater reliance on contract R&D in lieu of in-house performance, as well as intramural R&D in these industries.

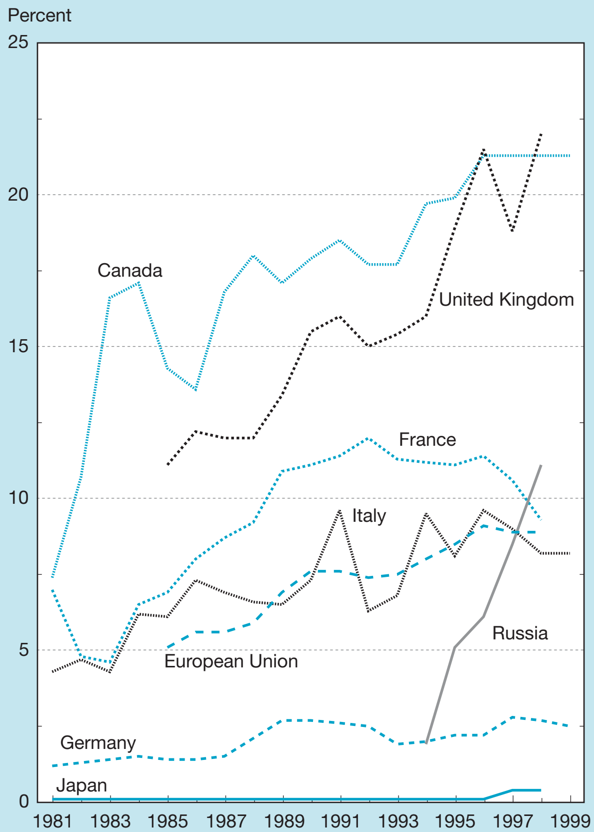
According to the national statistics, only in Germany and Japan do the nonmanufacturing sectors currently account for less than 10 percent of the industry R&D performance total. Among the countries listed in text table 4-16, services R&D shares range from as little as 4 percent in Japan to 59 percent in Russia. The latter figure, however, primarily occurs because specialized industrial research institutes perform a large portion of Russia's industry and federal government R&D and are classified under the "research and development" sector within the service sector. Apart from these institutes, the manufacturing-nonmanufacturing split in Russia's industrial R&D would be similar to ratios in the United States (American Association for the Advancement of Science (AAAS) and Centre for Science Research and Statistics (CSRS) 2001).

Source of Funds. Most of the industrial R&D in each of these eight countries is provided by industry itself. As is the situation for OECD countries overall, government financing accounts for a small and declining share of the industry R&D performance total within G-7 countries. See "Government Sector" for further discussion. Government financing shares range from as little as 2 percent of the industry R&D in Japan to 13 percent of Italy's industry R&D effort. (See appendix table 4-42.) (For recent historical reasons, Russia is the exception to this pattern among the G-8 countries, with government accounting for 43 percent of its industry total.) In the United States, the Federal Government currently provides about 11 percent of the R&D funds used by industry, and the majority of that funding is obtained through contracts from DOD.

As shown in figure 4-31, funds from abroad accounted for as little as 0.4 percent of Japan's R&D expenditure total to almost 22 percent of total R&D expenditures in the United Kingdom. Foreign funding, predominantly from industry for R&D performed by industry but also including some small amounts of foreign funding provided to other nonindustry sectors, is an important and growing funding source in several countries. Growth in this funding source primarily reflects the increasing globalization of industrial R&D activities overall. For European countries, however, the growth in foreign sources of R&D funds may also reflect the expansion of coordinated European Community (EC) efforts to foster cooperative shared-cost research through its European Framework Programmes.[64] Although the growth pattern of foreign funding has seldom been smooth, it now accounts for more than 20 percent of industry's domestic performance totals in Canada and the United Kingdom and approximately 10 percent of industry R&D performed in Italy, France, and Russia. (See figure 4-31.) Such funding takes on even greater importance in many of the smaller OECD countries as well as in less industrialized countries (OECD 1999b).

In the United States, approximately 13 percent of funds spent on industry R&D performance in 1998 are estimated to have come from majority-owned affiliates of foreign firms investing domestically. This amount was considerably more than the 3 percent funding share provided by foreign firms in 1980 and their 8 percent share reported as recently as 1991.[65]

Figure 4-31.
Proportion of industrial R&D financed by foreign sources



See appendix table 4-45.

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Government Sector

Government R&D Funding Totals. In most countries, the government sector makes its strongest impact on the R&D enterprise not by conducting R&D but, rather, by financing R&D. The government sector accounts for only 11 percent of OECD members' combined R&D performance in 1998 (OECD 2000a) and for 26 percent or (usually much) less in each of the G-8 countries. (See appendix table 4-42.) Government accounted for 13 percent of the OECD performance total as recently as 1995.

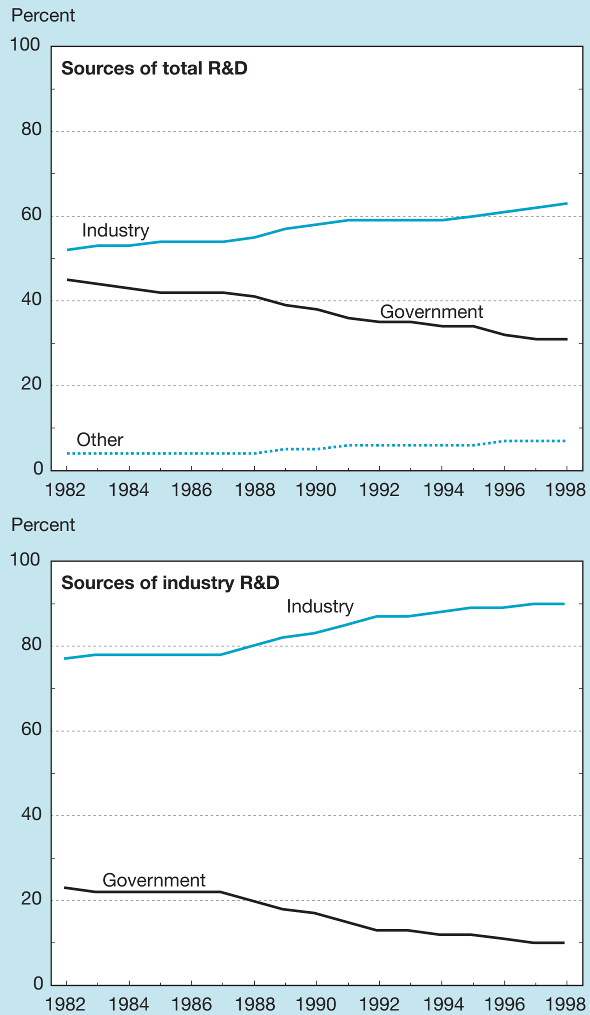
The decline in governments' share of the R&D performance totals, however, pales in comparison with their shrinking share of the R&D financing total. Indeed, the most significant trend among the G-7 and other OECD countries has been the relative decline in government R&D funding in the 1990s. In 1998, less than one-third of all R&D funds were derived from government sources, down considerably from the 45 percent share reported 16 years earlier. (See figure 4-32.) Among all OECD countries, government accounts for the highest funding share in Portugal (68 percent

[64]Since the mid-1980s, EC funding of R&D has become increasingly concentrated in its multinational Framework Programmes for Research and Technological Development (RTD), which were intended to strengthen the scientific and technological bases of community industry and to encourage it to become more internationally competitive. EC funds distributed to member countries' firms and universities have grown considerably. The EC budget for RTD activities has grown steadily from 3.7 billion European Currency Units (ECU) in the First Framework Programme (1984–87) to an estimated 15 billion ECU for the Fifth Framework Programme that runs from 1998 to 2002. The institutional recipients of these would tend to report the source as "foreign" or " funds from abroad" (Eurostat 2001).

[65]Unlike for other countries, there are no data on foreign sources of U.S. R&D performance. The figures used here to approximate foreign involvement are derived from the estimated percentage of U.S. industrial performance undertaken by majority-owned (i.e., 50 percent or more) nonbank U.S. affiliates of foreign companies. In short, the U.S. foreign R&D totals represent industry funding based on foreign ownership regardless of originating source, whereas the foreign totals for other countries represent flows of foreign funds from outside the country to any of its domestic performers. See the extensive coverage of industrial foreign R&D investments in the following sections of this chapter.

of its 1997 R&D total) and the lowest share in Japan (19 percent in 1998). Part of the relative decline reflects the effects of budgetary constraints, economic pressures, and changing priorities in government funding (especially the relative reduction in defense R&D in several of the major R&D-performing countries, notably France, the United Kingdom, and the United States). Another part reflects the absolute growth in industrial R&D funding as a response to increasing international competitive pressures in the marketplace, irrespective of government R&D spending patterns, thereby increasing the relative share of industry's funding as compared with government's funding. Both of these considerations are reflected in funding patterns for industrial R&D performance alone. In 1982, government provided 23 percent of the funds used by industry in conducting R&D within OECD countries, whereas by 1998 government's share of the industry R&D total had fallen by more than half, to 10 percent of the total. In most OECD countries (as in the United States), government support for business R&D is skewed toward large firms.

Figure 4-32.
Sources of R&D expenditures in OECD countries



OECD = Organisation for Economic Co-operation and Development

See appendix table 4-44.

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Government R&D Priorities. A breakdown of public expenditures by major socioeconomic objectives provides insight into government priorities that as a group have changed over time and that individually differ considerably across countries.[66] Within OECD, the defense share of governments' R&D financing total has declined annually since the mid-1980s. Accounting for 44 percent of the government total in 1986, defense-related activities now garner a much smaller 31 percent share. (See text table 4-17.) Much of this decline is driven by the U.S. experience: 53 percent of the U.S. Government's $78 billion R&D investment during 1999 was devoted to national defense, down from its 69 percent share in 1986. Nonetheless, defense still accounts for a relatively larger government R&D share in the United States than elsewhere. This share compares with the 35 percent defense share in the United Kingdom (of a $9 billion government total), 30 percent in Russia (of $4 billion), 23 percent in France (of $13 billion), and less than 10 percent each in Germany, Italy, Canada, and Japan. (See figure 4-33 and appendix table 4-43.) As in the United States, these recent figures represent substantial cutbacks in defense R&D in the United Kingdom and France, where defense accounted for 44 and 40 percent, respectively, of government R&D funding in 1990. However, defense-related R&D also seems particularly difficult to account for in many countries' national statistics. See sidebar, "Tracking R&D: Gap Between Performer- and Source-Reported Expenditures."

Concurrent with the changes in overall defense/nondefense R&D shares, notable shifts have occurred in the composition of OECD countries' governmental nondefense R&D support during the past two decades. In terms of the broad socioeconomic objectives to which government programs are classified in various international reports (OECD 1999a, 2000f), government R&D shares have increased most for health and the environment and for various nondirected R&D activities (identified in text table 4-17 as "other purposes").[67] Growth in health-related R&D financing has been particularly strong in the United States, whereas many of the other OECD countries have reported relatively greater growth for environmen-

[66]Data on the socioeconomic objectives of R&D funding are rarely obtained by special surveys; they are generally extracted in some way from national budgets. Because those budgets already have their own methodology and terminology, these R&D funding data are subject to comparability constraints not placed on other types of international R&D data sets. Notably, although each country adheres to the same criteria for distributing their R&D by objective as outlined in OECD's *Frascati Manual* (OECD 1994), the actual classification may differ among countries because of differences in the primary objective of the various funding agents. Note also that these data reflect government R&D funds only, which account for widely divergent shares and absolute amounts of each country's R&D total.

[67]Health and environment programs include human health, social development, protection of the environment, and exploration and exploitation of the Earth and its atmosphere. R&D for "other purposes" in text table 4-17 includes nonoriented programs, advancement of research, and primarily GUF (e.g., the estimated R&D content of block grants to universities described in note 56).

Text table 4-17.
Government R&D support for defense and nondefense purposes, all OECD countries
(Percentages)

	Government R&D budget shares		Government nondefense R&D budget shares			
Year	Defense	Nondefense	Health and environment	Economic development programs	Civil space	Other purposes
1981	35.6	64.4	19.7	37.5	9.9	32.9
1982	38.1	61.9	19.4	37.7	8.6	34.3
1983	39.9	60.1	19.3	36.8	7.7	36.2
1984	41.8	58.2	20.1	35.9	7.9	36.1
1985	43.4	56.6	20.5	35.6	8.6	35.3
1986	44.4	55.6	20.5	34.5	8.8	36.2
1987	44.1	55.9	21.2	32.3	9.8	36.7
1988	43.4	56.6	21.5	30.7	10.2	37.6
1989	42.0	58.0	21.8	29.9	11.0	37.3
1990	40.2	59.8	22.3	29.0	12.1	36.6
1991	37.3	62.7	22.3	28.6	12.2	36.9
1992	36.0	64.0	22.6	27.5	12.3	37.6
1993	36.0	64.0	22.5	26.6	12.5	38.4
1994	33.5	66.5	22.7	25.6	12.6	39.1
1995	31.6	68.4	22.7	24.6	12.3	40.4
1996	31.3	68.7	22.8	24.5	12.0	40.7
1997	31.3	68.7	23.1	24.7	11.6	40.6
1998	30.5	69.5	23.9	22.7	11.5	41.9

SOURCE: Organisation for Economic Co-operation and Development (OECD), Main Science and Technology Indicators database (Paris, November 2000).

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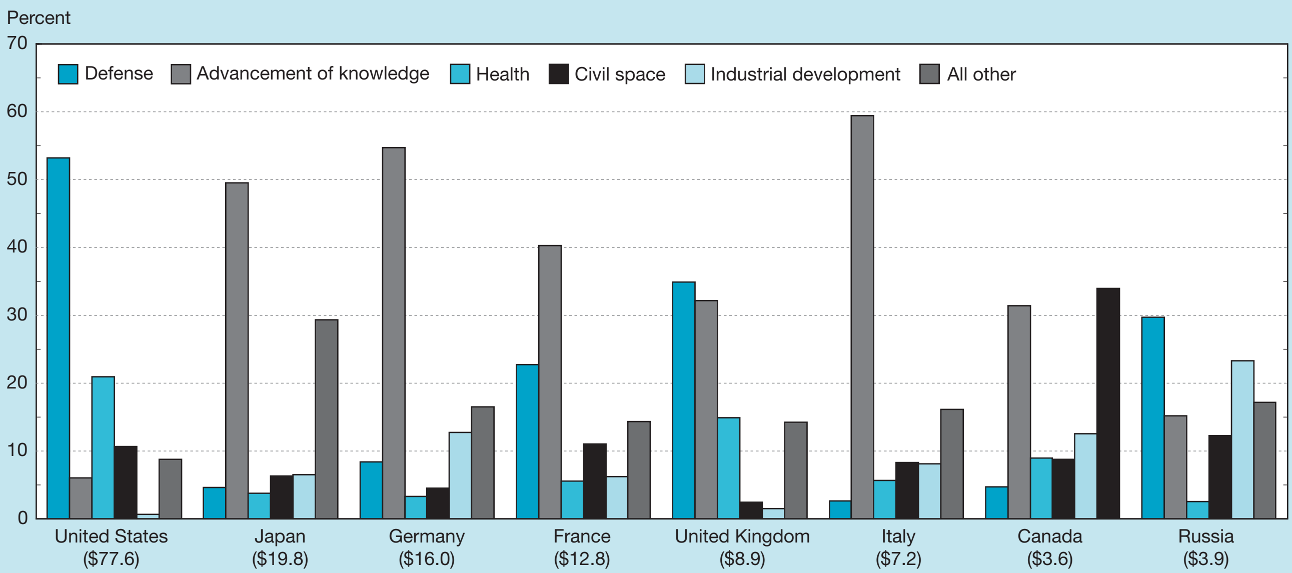
Figure 4-33.
Government R&D support by socioeconomic objectives, G-8 countries



NOTES: The amounts listed under country names represent total government R&D support in billions of U.S. purchasing power parity (PPP) dollars. Data for Italy, Russia, and Canada are for 1998; data for all other countries are for 1999. R&D is classified according to its primary government objective, although it may support any number of complementary goals. For example, defense R&D with commercial spinoffs is classified as supporting defense, not industrial development. R&D for the advancement of knowledge is not equivalent to basic research.

See appendix table 4-43.

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Tracking R&D: Gap Between Performer- and Source-Reported Expenditures

In many OECD countries, including the United States, total government R&D support figures reported by government agencies differ substantially from those reported by performers of R&D work. Consistent with international guidance and standards (OECD 1994), however, most countries' national R&D expenditure totals and time series are based primarily on data reported by performers. This convention is preferred because performers are in the best position to indicate how much they spent in the actual conduct of R&D in a given year and to identify the source of their funds. Although funding and performing series may be expected to differ for many reasons such as different bases used for reporting government obligations (fiscal year) and performance expenditures (calendar year), the gap between the two R&D series has widened during the past several years. Additionally, the divergence in the series is most pronounced in countries with relatively large defense R&D expenditures (National Science Board (NSB) 1998).

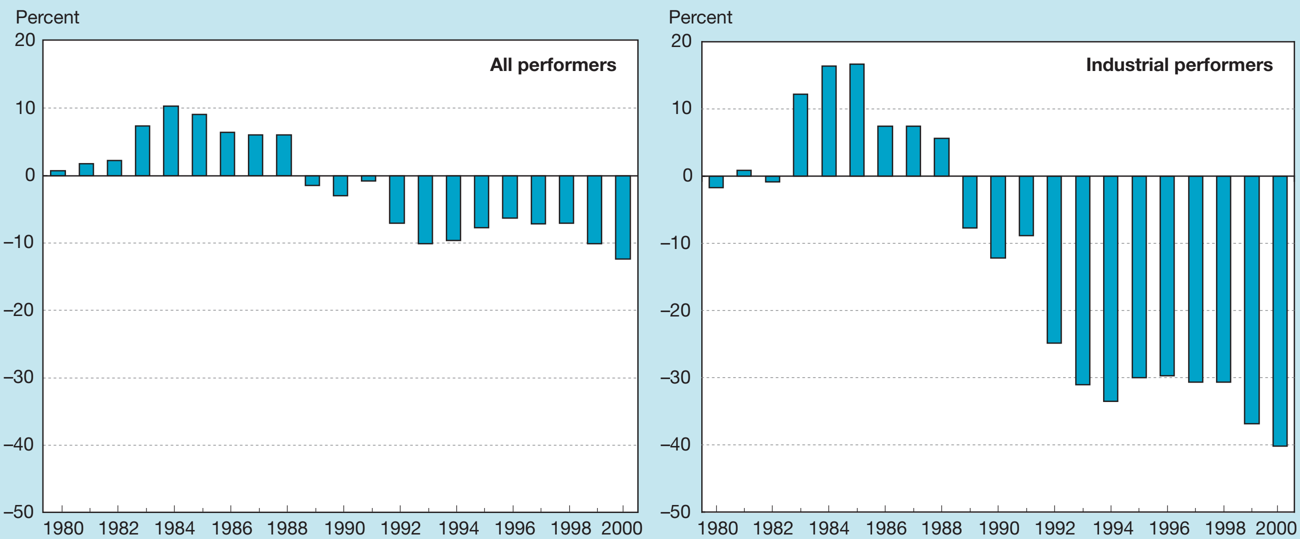
Data Gap Trends

For the United States, the reporting gap has become particularly acute over the past several years. In the mid-1980s, performer-reported Federal R&D exceeded Federal reports by \$3 to \$4 billion annually (5–10 percent of the government total). This pattern reversed itself toward the end of the decade; in 1989, the government-reported R&D total exceeded performer reports by \$1 billion. The gap has since grown to about \$8 billion. In other words, approximately 10 percent of the government total in 1999 is unaccounted for in performer surveys. (See figure 4-34.) The difference in Federal R&D totals is primarily in Department of Defense (DOD) development funding of industry (principally aircraft and missile firms). For 1999, Federal agencies reported \$31.9 billion in total R&D obligations provided to industrial performers compared with an estimated \$20.2 billion in Federal funding reported by industrial performers. (DOD reports industry R&D funding of \$24.6 billion, whereas industry reports using \$11.7 billion of DOD's R&D funds.) Overall, industrywide estimates equal a 37 percent paper "loss" of federally reported 1999 R&D support. (See figure 4-34.)

Reasons for Data Gaps

Interviews with industry representatives have helped the National Science Foundation (NSF) identify possible reasons that performer-reported R&D totals might differ from funding agency-reported totals. Generally, since the end of the cold war, numerous changes have occurred in the defense contracting environment and DOD's budgeting process. These have been accompanied by major shifts in the composition of R&D, test, and evaluation contracts, which may account for some of the statistical discrepancies. In ways unknown a decade earlier, new types of defense contractors and nontraditional forms of R&D expenditures apparently play a major role in complicating the collection of R&D data. (A complete summary of the NSF study appeared in NSB 2000.)

Figure 4-34.
Difference in U.S. performer-reported versus agency-reported Federal R&D



NOTE: Difference is defined as percentage of federally reported R&D.

See appendix table 4-34.

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More recently, however, Federal agencies and representatives from firms and universities (recipients of Federal R&D funding) gathered at a Congressional Research Service (CRS) workshop to discuss these R&D data issues. Not surprisingly, participants were unable to reach a consensus on the reasons for the growing data gaps. According to the CRS summary (Davey and Rowberg 2000), participants generally agreed that agency downsizing in recent years has left fewer resources to collect, process, and report R&D data to NSF. Because agencies do not place a high priority on such data reporting, those who report data are likely to be the early victims of downsizing. Nonetheless, the agencies with the largest discrepancy between their reported R&D obligations and the R&D expenditures reported by industry performers receiving those funds (DOD, Department of Energy, and National Aeronautics and Space Administration) believe that the source of the discrepancy lies almost exclusively with the performers. Those agencies have reviewed their data collection and reporting methods and contend that they have been stable and consistent over the period during which the discrepancies have grown.

On the other hand, the U.S. Bureau of the Census, which collects the industry R&D data for NSF, stated that it has not seen any significant shifts in the character of that data since at least 1992. In particular, no significant changes have appeared that could correlate with the rise in mergers and acquisitions among the surveyed firms. Industry participants questioned why agencies were not solely responsible for reporting these Federal R&D funding data to NSF rather than sharing the burden with industry. And according to an even more recent U.S. General Accounting Office (2001a) investigation, "Because the gap is the result of comparing two dissimilar types of financial data [Federal obligations and performer expenditures], it does not necessarily reflect poor quality data, nor does it reflect whether performers are receiving or spending all the Federal R&D funds obligated to them. Thus, even if the data collection and reporting issues were addressed, a gap would still exist." In summary, users should expect no quick resolution to the issue of why performer-reported R&D data differ from the data reported by the funding Federal agencies, nor perhaps should they be overly concerned about the discrepancy.

tal research programs. Indeed, as is indicated from a variety of R&D metrics, the emphasis on health-related research is much more pronounced in the United States than in other countries, although the importance of tracking the R&D contribution to improving human health has become widely accepted (OECD 2001a). In 1999, the Federal Government devoted 21 percent of its R&D investment to health-related R&D, making such activities second only to defense. (Direct comparisons between health and defense R&D are complicated because most of the health-related R&D is research, and about 90 percent of defense R&D is development.)

The relative shift in emphasizing nondirected R&D reflects government priority setting during a period of fiscal austerity and constraint. With fewer discretionary funds available to support R&D, governments have tended to conduct activities that are traditionally in the government sphere of responsibility and for which private funding is less likely to be available. For example, basic research projects are inextricably linked to higher education.[68] Conversely, the relative share of government R&D support provided for economic development programs has declined considerably, from 38 percent of total in 1981 to 23 percent in 1999. Economic development programs include the promotion of agriculture, fisheries and forestry, industry, infrastructure, and energy, all activities for which privately financed R&D is more likely to be provided without public support, although the focus of such private and public support would undoubtedly differ somewhat.

Different activities are emphasized in individual countries' governmental R&D support statistics. Japan committed 19 percent of its total governmental R&D support ($20 billion) to energy-related activities, reflecting the country's historical concern about its high dependence on foreign sources of energy. (See appendix table 4-43.) In Canada, 11 percent of the government's $4 billion in R&D funding was directed toward agriculture. Space R&D received considerable support in the United States and France (11 percent of the total in each country), while industrial development accounted for 8 percent or more of governmental R&D funding in Canada, Germany, Italy, and Russia. In fact, industrial development is the leading socioeconomic objective for R&D in Russia, accounting for 23 percent of all government R&D, funding for which is primarily oriented toward the development of science-intensive industries and is aimed at increasing economic efficiency and technological capabilities (AAAS and CSRS 2001).[69] Industrial development programs accounted for 7 percent of the Japanese total but for less than 1 percent of U.S. R&D. (See figure 4-33.) The latter figure, which includes mostly R&D funding by NIST of the U.S. Department of Commerce, is understated relative to most other countries as a result of data compilation differences. In part, the low U.S. industrial development share reflects the expectation that firms will finance industrial R&D activities with their own funds; in part, government R&D that may be indirectly useful to in-

[68]See Kaiser et al. (1999) for a description on recent efforts to make higher education R&D data more internationally comparable.

[69]As an added indication of evolving government priorities in Russia, fully 27 percent of the government's 1998 R&D budget appropriations for economic programs were used to assist in the conversion of the country's defense industry to civil applications (AAAS and CSRS 2001).

dustry is often funded with other purposes in mind such as defense and space (and is therefore classified under other socioeconomic objectives).

Japanese, German, and Italian government R&D appropriations in 1998–99 were invested relatively heavily in advancement of knowledge (50 percent or more of the $20 billion total for Japan, 55 percent of Germany's $16 billion total, and 59 percent of the $7 billion total in Italy). "Advancement of knowledge" is the combined support for advancement of research and GUF.[70] Indeed, the GUF component of advancement of knowledge, for which there is no comparable counterpart in the United States, represents the largest part of government R&D expenditure in most OECD countries.

R&D Tax Policies. In many OECD countries, government not only provides direct financial support for R&D activities but also uses indirect mechanisms such as tax relief to promote national investment in S&T. Indeed, tax treatment of R&D in OECD countries is broadly similar, with some variations in the use of R&D tax credits (OECD 1996, 1999a). The main features of the R&D tax instruments are as follows:

- Almost all OECD countries (including the United States) allow 100 percent of industry R&D expenditures to be deducted from taxable income in the year they are incurred.
- About one-half of OECD countries (including the United States) provide some type of additional R&D tax credit or incentive with a trend toward using incremental credits. A few countries also use more targeted approaches, such as those favoring basic research.
- Several OECD countries have special provisions that favor R&D in small and medium-size enterprises. (In the United States, credit provisions do not vary by firm size, but direct Federal R&D support is provided through grants to small firms.)

A growing number of R&D tax incentives are being offered in OECD countries at the subnational (provincial and state) levels, including in the United States. See Poterba (1997) for a discussion of international elements of corporate R&D tax policies.

International Industrial R&D Investments

International R&D investments refer to R&D and related long-term activities by private companies outside of the home country. Broadly speaking, these activities include the acquisition or establishment of R&D facilities abroad, R&D spending in foreign subsidiaries (in manufacturing, services, or research facilities), international R&D alliances, licensing agreements, and contract research overseas. These activities fulfill different objectives in corporate R&D strategies and exhibit various degrees of managerial and financial commitment from the parties involved. Although public data on these international business activities are key for S&T policy analysis and design, their availability varies considerably, even within advanced economies.

In this section, the focus is on R&D spending trends to and from the United States, with a brief overview of overseas and foreign-owned domestic R&D facilities.[71] In principle, trends in R&D facilities are tied to overall foreign direct investment (FDI) trends, especially in high-technology industries. However, comprehensive FDI data on acquired and established facilities by type of major activity (i.e., manufacturing versus research) are not available in most countries.[72] On the other hand, R&D spending by multinational corporations are readily available from financial and operating data collected in FDI statistics.

By definition, R&D spending in subsidiaries abroad is preceded by the acquisition or establishment of foreign facilities. More fundamentally, however, the economics of these two activities have become increasingly intertwined in advanced economies. For one, FDI flows are becoming a key element in understanding the overall corporate R&D strategy of global companies. Conversely, knowledge-based assets are becoming an increasingly important factor in FDI decisions by multinational companies. However, empirical links are elusive with the available data. For example, mere changes in ownership can affect R&D spending statistics without representing changes in the actual performance of R&D domestically.

Foreign Direct Investments and R&D Facilities

Total foreign direct investments have increased steadily in recent years in the United States and elsewhere, according to data from the Bureau of Economic Analysis (BEA). Recent increases worldwide have been fueled by motives ranging from market liberalization efforts leading to privatization drives in some emerging markets, proximity to existing or potential large consumer markets, and regional technological advantages. Foreign direct investment flows into the United States are dominated by the lure of a large domestic market and by the technological sophistication of many of its firms. Technology-related factors driving FDI include an educated and skilled workforce, a favorable regulatory environment, and the need for complementary technologies in an increasingly complex and rapid innovation process.

According to an OECD study, as much as 85 percent of FDI activity worldwide consists of mergers and acquisitions (M&As), compared to the establishment of new industrial facilities or so-called greenfield investments (Kang and Johansson

[70] In the United States, "advancement of knowledge" is a budgetary category for research unrelated to a specific national objective. Furthermore, although GUF are reported separately for Japan, Canada, and European countries, the United States and Russia do not have an equivalent GUF category. In the United States, funds to the university sector are distributed to address the objectives of the Federal agencies that provide the R&D funds. GUF is not equivalent to basic research. For 1999, the GUF portion of total national governmental R&D support was 48 percent in Italy, 39 percent in Germany, 37 percent in Japan, and between 18 and 24 percent in the United Kingdom, Canada, and France.

[71] Data limitations preclude the inclusion of contract R&D with (or grants to) foreign organizations, whereas international technology alliances are discussed earlier in this chapter.

[72] As discussed below, a DOC survey with 1997 and 1998 data provides the latest available indicators of overseas and foreign-owned domestic R&D facilities.